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Evaluation of consecutive skylines yarding and gravity skidding systems in primary forest transportation on steep terrain

Selcuk Gumus* and H. Hulusi Acar

Department of Forest Engineering, Faculty of Forestry, Karadeniz Technical University, 61080, Trabzon, Turkey

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Abstract: *This investigation evaluates two primary forest transportation systems, consecutive skyline yarding system integrated with two different types of skyline yarding systems and the gravity skidding system, considering technical, economical and environmental aspects. The results indicated that the productivity of consecutive skyline yarding system was 4.97 m^3 hr^{-1}, while the productivity of the gravity skidding system was 0.74 m^3 hr^{-1}. The unit costs of these primary transportation systems were found to be \$5.98 and \$51.28 m^3, respectively. Besides, the gravity skidding system caused more damages on skidded logs, residual trees, and forest soil than that of consecutive skyline yarding system. It was also indicated that two different skyline yarding systems produced definite and different average yarding distances and technical capacities, which negatively affected the overall performance of the consecutive skyline yarding system. Therefore, different types of skyline yarding systems should not be integrated into the consecutive yarding systems.*

Key words: *Forest transportation, Skyline yarding, Gravity skidding, Steep terrain, Environmental damages, Productivity*
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* **Corresponding author:** sgumus@ktu.edu.tr

Introduction

The main objective of the primary transportation stage in timber harvesting operations is to move either the tree or segments of the tree from the stump location to a collection point called landings. The primary transport of forest products is a very difficult, expensive and time-consuming operation. This issue is especially important for Turkish forestry because approximately 75% of the forested areas are on steep and mountainous areas with slopes greater than 40%. Planning and implementing harvesting methods in the mountainous regions has always required a particular consideration (Senturk *et al.,* 2007; GDF, 2005). Otherwise, inappropriate and poorly planned methods used for primary transportation stage may result in serious adverse effects on timber quality, residual trees, forest soil, and forest productivity (Acar and Yoshimura, 1997; Akay *et al.,* 2007; Demir *et al.,* 2007; Wang *et al.,* 2005; Wang *et al.,* 2004).

There have been several methods used to accomplish primary transportation in steep terrains of Turkey. One of the common methods is the aerial systems using skyline yardings where the machine does not remain in contact with the ground and the cut trees remain fully suspended in the air (Kellogg *et al.,* 1996). The other method is the gravity skidding, which is a primitive transport system not utilizing any machine power. In this system, logs are skidded on the ground surface by the power of their weight and the earth's gravity.

Skyline yarding systems have the potential to minimize site and stand impacts on sensitive sites (Thompson *et al.,* 1998) and to reduce soil erosion and damages on young trees that are left (Camp, 2002). Usage of skyline yarding systems dates back to 1980s in Turkey; however, continuous technical and practical education has not been sufficiently established. For this reason, the staffs of local forest offices generally operated skyline yarding according to their experiences and best judgments. The consecutive skyline yarding system, integrating different types of skyline yarding systems, has also been experimented during primary transportation of forest products. These usages were originated by possibilities of their machine park capacity, terrain conditions, and the harvesting quotas of local offices.

There are number of studies that investigated the productivity and cost of skyline yarding systems in the eastern Black Sea region of Turkey. The results from these studies indicated that the average productivity and cost of skyline yarding system using Koller K300 model yarder was calculated as 4.2 and \$ 7 m^3 hr^{-1}, respectively. These results were observed at 45% average side slope with 300 m average yarding distance. Productivity of Gantner model yarder was calculated as 3.77 m^3 hr^{-1} for a yarding system with 1500 m average yarding distance operating on 45% side slope (Acar, 1997; Acar and Erdas, 1992; Acar and Yoshimura, 1997; Erdas, 1989; Erdas and Eroglu, 1999; Senturk *et al.,* 2007).

In this study, two primary forest transportation systems; 1) consecutive skyline yarding system integrated with two different types of skyline yarding systems and 2) the gravity skidding system based on previously conducted studies in the region were evaluated subject to technical, economical and environmental aspects. The skyline yarding systems established by Savsat Forest Office (SFO) at Misirli region in the city of Artvin were selected in this study due to lack of previous experimental works and scientific researches in this region.

The aims of this case study were to evaluate the performance of the consecutive skyline system established by local office staff, to make a decision about the capability of combining the skylines together and to provide scientific results for practitioners and researchers. It was also aimed to determine the most suitable primary transportation method for the Misirli region by evaluating the gravity skidding method as an alternative transportation technique.

Materials and Methods

The study area was located at Misirli region of Savsat Forest Enterprice, Artvin Regional Forestry Directorate, in the eastern Black Sea region of Turkey (Fig. 1).

The harvesting unit of 163.25 ha consisted of 238th, 239th, and 271st forest compartments located in steep mountainous areas of the Misirli region. In the study area, approximately 2000 m^3 logs of *Picea orientalis* (L.) Link and *Abies nordmanniana* Spach species were transported at final cutting. The average stand age is approximately 100 yrs. Average terrain slope was 70% with the average skidding distance of 900 m. Terrain condition on the skidding paths was rough and stony, with some rock blocks. The existing forest road at the valley base was not sufficient to provide access to the whole harvesting site.

The digital data layers of the study area, including Digital Elevation Model (DEM), existing forest road network, new planned forest roads, stream channels and yarding corridors, were generated by using the topographic map, forest management plans, and field measurements of the harvesting site (Fig. 2).

The local forest office staff decided to layout a long-distance forest skyline yarding system for primary transportation, however, the length of the main skyline cable was not long enough for the long-distance skyline to reach as far as the roadside ramp. Thus, a consecutive skyline yarding system, divided by an intermediate ramp, was established (Fig. 3).

In the consecutive skyline system, logs were initially transported from up-hill station to the intermediate ramp with a Gantner model yarder. Then, the logs unhooked at the intermediate station were transported to the down-hill station with Koller K300 model yarder for completion of cable extraction operations.

Total skyline distance from uphill station to intermediate station was 1400 m with the average yarding distance of 700 m. Skyline with the slope of 70% was elevated for four points with an "M" hanger pylon. Koller K 300 yarder was located on roadside ramp was 200 m away from the intermediate station, with the skyline slope of 10%.

This study was intended to evaluate primary transportation in the Misirli region with regard to technical, economic and environmental aspects. The consecutive skyline system and gravity skidding systems that can act as an alternative opening-up method across the skyline system were investigated. In the evaluation phase, these two transportation systems were compared with each other.

In the analysis, the consecutive skyline system was investigated by evaluating integrated skyline yarding systems separately. The productivity and unit costs of the skylines was calculated based on the average cycle time by using a continuous time study technique. Time studies were made during productive work hours in September from 8.00 in the morning to 17.00 in the afternoon. Field studies were performed at an average elevation of 1500 m during the daily temperature of 10 ^{o}C.

In time studies, delay time due to machine-down time and other operational difficulties were considered in cycle-time calculations. In addition, lateral yarding distance, number of logs per cycle, total yarded log volume, and average middle diameter per log were measured for the calculation of productivity and cost of yarding operation. In the determination of total cycle-time, statistical methods were used and results were analyzed with T value and F test (Kalipsiz, 1981).

There are numerous approaches for estimating unit costs of timber harvesting (Keegan *et al.,* 2002). In this study, the method used for cost analysis was implemented from FAO (1992). This method was based on fixed and variable expenditure (FAO, 1992). Purchase cost of yarders was provided by General Directorate of Forestry (GDF) for calculating yarder costs. All the values used in cost analysis were converted from TRY to the USD ($). Operator fees were obtained from the records of Savsat Forest Office (SFO). Considering the ecological and topographical conditions of the region, yearly working day were estimated as 250 d on average. Daily work time was accepted as 8 hr. The average machine life time for yarders was considered as 10000 hr (5 yrs) (Seckin, 1982). Skidding cost and log-selling price were also obtained from SFO.

The gravity skidding as an alternative primary transportation method in the study area was investigated based on the earlier studies performed in the same region with the same forest types and topographical characteristics. The results from these previous studies were implemented to compute skidding time, productivity, operational costs, and forest road construction cost. The economical analysis was conducted based on the 2006 data of GDF (Acar, 1994; GDF, 2007).

Since the gravity skidding method definitely needs sound forest road network, the existing forest roads were investigated in the study area. The results indicated that there are not enough forest roads to effectively apply the gravity skidding method. Thus, a comprehensive forest road network was designed for the logging site as suggested by Heinimann (1998). GIS techniques and a digital database were used in the layout and evaluation processes of forest roads. The roads were constructed in Type B forest road

Fig. 1: Study area of Misirli region in savsat forest enterprice

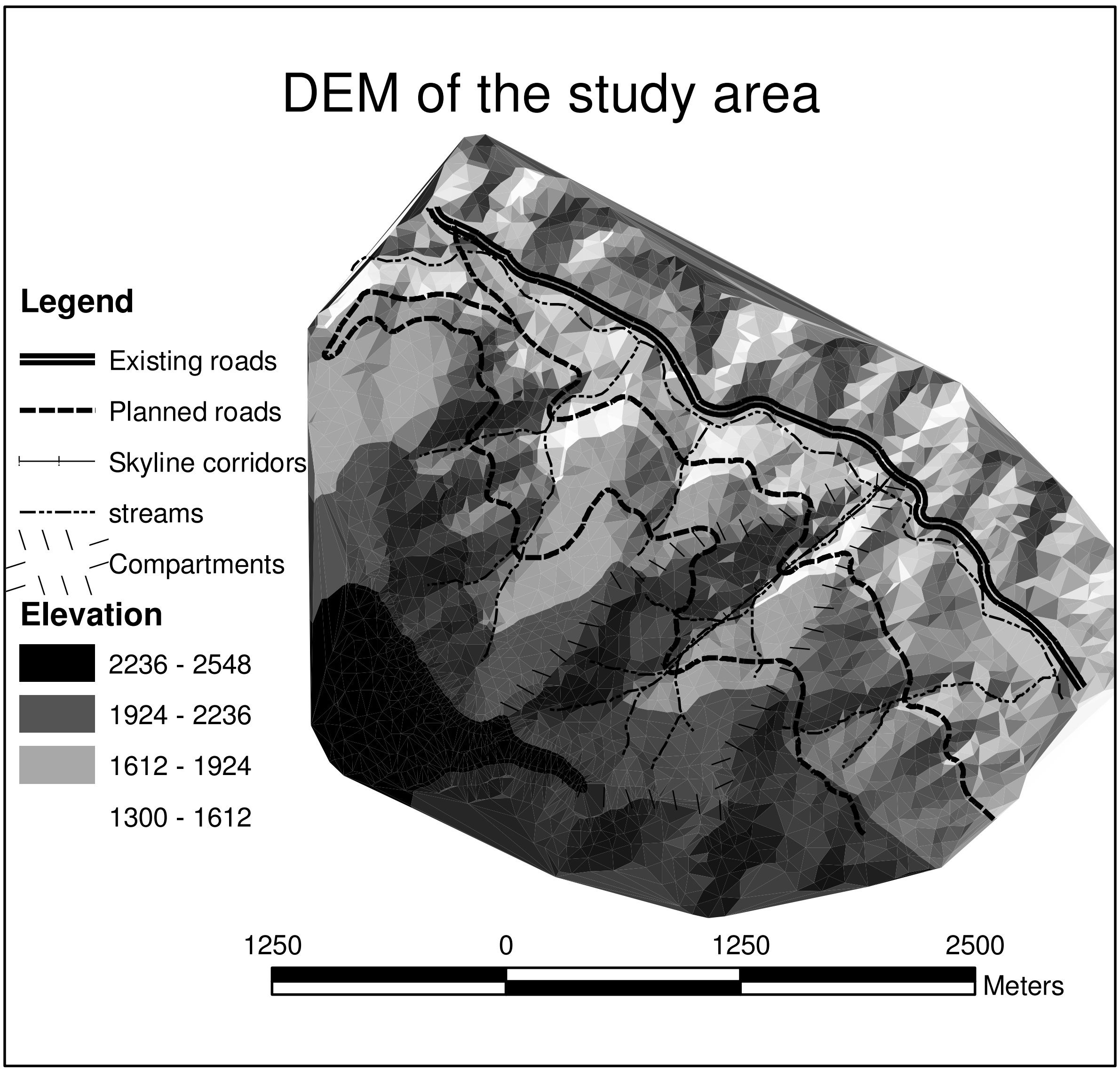

Fig. 2: DEM of the study area indicating forest roads, stream channels and yarding corridor

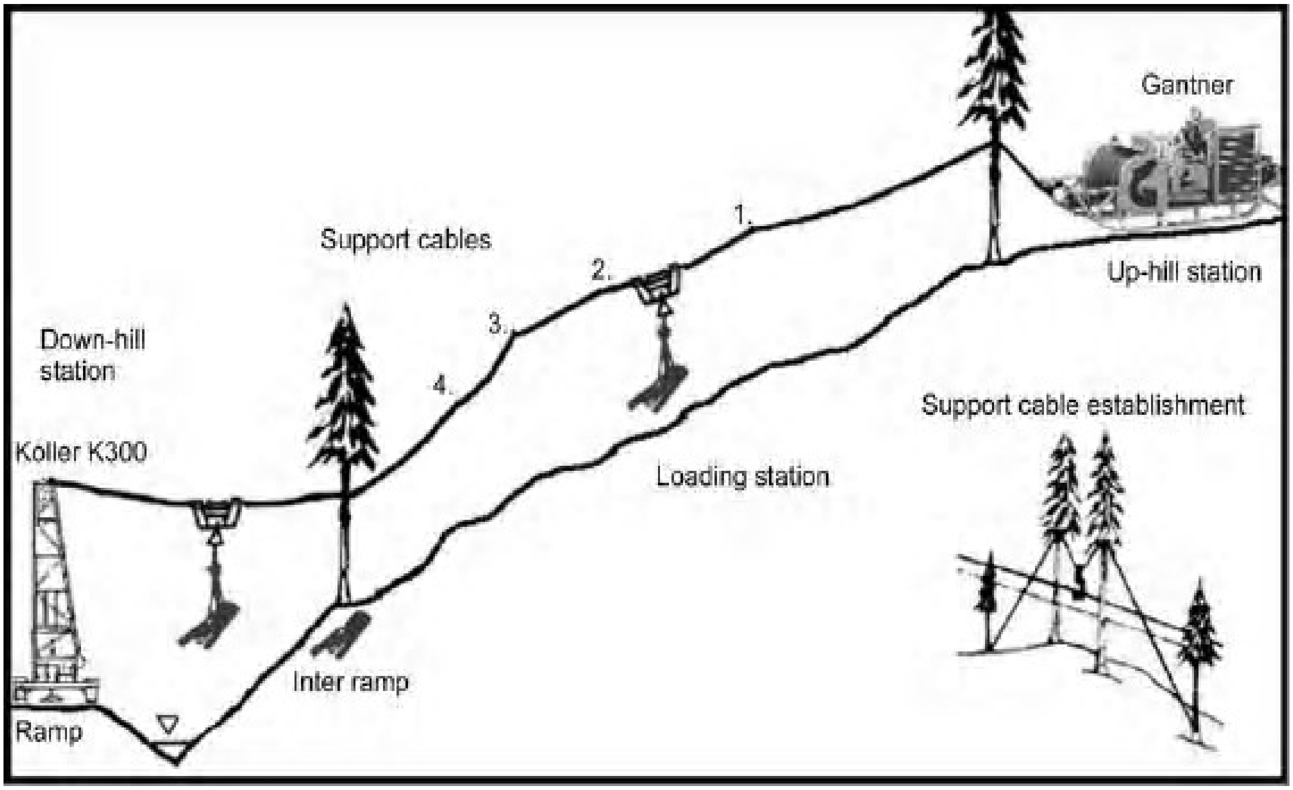

Fig. 3: Operation of the consecutive yarding system

standards; 4 m platform wide, 1 m drainage ditch, max 12% vertical gradient, min 20 m curve radius, and stone pieces pavement. Harvesting methods and other forestry activities were taken into account during planning operations (Acar and Gumus, 1999).

The unit cost data from SFO records were used to calculate the total construction costs of required forest roads. Average adjudication price was estimated by office staff by implementing the cost data of sample forest roads previously built on the same terrain conditions. Then, adjudication price of one km of forest road was calculated as approximately $ 26700.

The negative effects of road construction on nature were also considered by estimating the forested area, which will be disturbed by forest road construction. This was calculated by multiplying the road length by the width of the road construction area (20 m).

Results and Discussion

Time study and field measurements were separately carried out for Gantner and Koller K300 yarders based on data obtained from 36 and 39 yarding cycles, respectively. For Gantner yarder, the total time was found to be 27.40 min cycle^{-1} and average productivity was 2.27 m^3 cycle^{-1} (4.97 m^3 hr^{-1}). For the Koller K 300 yarder, the total time was found to be 10.24 min cycle^{-1} and productivity was 1.35 m^3 cycle^{-1} (7.86 m^3 hr^{-1}) (Table 1). Thus, the total time spent on transporting one m^3 log from the stump to the roadside ramp was 19.95 min m^{-3} at consecutive work of skyline.

Table - 1: Productivity summary of cable yarding systems by Gantner and Koller K300 yarder

Productivity	Gantner	Koller K300
Total volume (m^3)	81.6	54.21
Total cycles	36	39
Average volume per cycle (m^3)	2.27	1.39
Total No. of pieces	265	128
Volume per piece (m^3)	0.31	0.42
Average No. of pieces per cycle	7.36	3.26
Average log diameter (cm)	40.44	46.52
Average yarding distance (m)	700	200
Average lateral distance (m)	30	5
Average time per cycle (minute)	27.40	10.24
Average time per m^3 (minute)	12.09	7.86
Productivity	2.27 m^3 cycle^{-1}, 4.97 m^3 hr^{-1}	1.35 m^3 cycle^{-1} 7.86 m^3 hr^{-1}

Table - 2: Gantner and Koller K30 yarders operation cost summary

Cost component	Costs	
	Gantner	Koller K300
Total Fixed Expenditure ($ hr^{-1})	13.36	13.91
Total Variable Expenditure ($ hr^{-1})	4.443	5.01
General Total ($ hr^{-1})	17.81	18.92
Average Productivity (m^3 hr^{-1})	4.969	7.860
General Cost ($ m^{-3})	3.58	2.40

$ = USD

Table - 3: Comparisons of operation parameters between consecutive skyline system and gravity skidding methods

	Consecutive skyline system (5 workers)	Gravity skidding (5 workers)
Transport time (min. m^{-3})	19.95	81.08
Productivity (m^3 hr^{-1})	4.97	0.74
Unite cost (\$ m^{-3})	5.98	51.28
Total work time (hr)	598.33	2702.66
Total harvesting cost (\$)	3578.01	102560
Site impacts	There is not significant damages	Marked damages on logs, residual stands and forest soil

$ = USD

The productivity of the consecutive system (4.97 m^3 hr^{-1}) was equal to that of the Gantner skyline. Koller K300 productivity was higher than the Gantner which could not work with full capacity. Besides, in the yarding operation, the Koller K300 pulled logs directly from the intermediate ramp under the main cable, while the Gantner skyline yarded logs from 30 m lateral distance.

According to the results shown in Table 1, there are clear differences in whole values between two skyline systems. Thus, the time it takes each skyline to transport one m^3 log should be investigated separately to define the technical suitability of the consecutive skyline system. One m^3 log was transported within 12.09 min. from the up-hill station to intermediate station using Gantner yarder. Koller K300 skyline transported logs within 7.86 min. from intermediate station to down-hill station at roadside. It should be considered that the logs yarded to roadside ramp by Koller K300 were then loaded to trucks right after unloading them from the yarder carriage. To ensure efficiency and productivity, this process must be done synchronously because of the lack of landing space at roadside. Therefore, the truck loading time were calculated (12.5 min m^{-3}) as suggested by Acar (1998) and added onto the transportation time of Koller K300 for this case study. The transportation plus loading time of one m^3 log was computed as 20.36 min.

It is clear that there are two transport stages and each stage has different transportation time. In the first stage (Gantner), transportation time was 12.09 min, while transportation and truck loading time was 20.36 min in the second stage (Koller K300). According to these results, the consecutive work system could not meet technical requirements because there was an accumulation of logs at the intermediate ramp. No damage to logs or forest soil, except pre-skidding up to the main cable, was observed while skyline yarding was in operation.

The system cost was calculated and all values in cost analysis were converted from TYR to \$ (1 \$ = 1.4 TYR year 2006) (TurkStat 2007). Operator and worker fees are \$ 654.2 and \$ 532.8, respectively. Fuel consumptions were 1.6 liter hr^{-1} and 2.00 liter hr^{-1} for Gantner and Koller K 300 yarders, respectively. Yarders' cost analysis is summarized in Table 2.

The cost results found in this study presented good agreement with results from the previous studies that have been conducted on total cycle-time and cost calculations of various yarding operations (Akay 2004; Huyler and LeDoux 1997; Visser *et al.* 2001; Visser and Stampfer 1998; Tunay and Melemez 2001). There were insignificant differences in cost values due to changed exchange rates between the currencies. Technical, economic and site impact results obtained from two primary log transportation methods were summarized in Table 3.

The gravity skidding technique that could be used for alternative opening-up requires 2.375 km of forest road for the harvesting site. These roads mean that a total of 80% of the area is to be opened up for harvesting. Average skidding distance between roads was calculated as 250 m with the 70 % slope of skid roads. Twenty percent of the skid road was located in rocky surface and 40% of the road was covered by bush. Total forest road cost was approximately \$ 65000 with the unit cost of \$32.5 m^{-3}.

The time study of the Gravity skidding system was evaluated based on the areas with similar terrain conditions of the study area. The productivity of this system was found to be 1.174 m^3 day^{-1} worker (0.74 m^3 hr^{-1} 5 $workers^{-1}$) for 250 m of skidding distance and 65% of side slope (Acar, 1994). The cost of gravity-skidded one m^3 timber was calculated as \$18.78 (GDF 2007) for the Artvin region. From these results, the total cost of the gravity skidding method was calculated as \$ 51.28 m^{-3}.

The gravity skidding method needed 2.375 km of forest road, which would result in the loss of 4.75 ha forested area. Besides, quality reduction on skidded logs and soil losses on skid trails could occur (Sidle *et al.*, 2004; Wang *et al.,* 2004).

The results of the soil disturbance assessment clearly showed that skyline cable yarding results in much less soil impact than that of other common systems for steep slope site harvesting (Wang *et al.,* 2005). It would also be logical to assume that less soil erosion, sedimentation and timber productivity impact would occur on cable-yarded sites than on sites harvested with ground-based systems. Access to sites with very sensitive soils is also more feasible throughout the year with cable yarding systems than with ground-based systems.

Usage of forest skylines is more productive and more economical than the gravity skidding in primary transportation of forest products. Beside, skylines systems are more environmentally friendly because there is no contact between logs and ground. In skyline systems, it was not observed any significant negative effect on logs, remain stands, or forest soils. According to all evaluations, forest skyline should be used as the primary transportation method in the Misirli region harvesting site. On the other hand, it is essential that the skylines should be used according to their technical capacities. Besides, different types of forest skylines should not be used in consecutive skyline yarding systems. Skylines should be used separately, instead. Before establishment of forest skylines, harvesting sites must be analyzed and skyline layout location should be carefully defined.

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